

HYDROMETEOR DEVELOPMENT IN COLD CLOUDS IN FIRE

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1. INTRODUCTION

The role of cirrus clouds, particularly in weather and climate processes, has been increasingly investigated. Numerical models have demonstrated the importance of the solar reflectivity and infrared radiation of cirrus clouds in the earth's radiation budget and climate. These properties depend upon the cloud microphysical characteristics, density, and altitude and hence justify investigation. The results reported herein were obtained from cold clouds (-20 to -46°C) in the mid to upper troposphere during ten flights of the NCAR King Air as part of the First ISCCP Research Experiment (FIRE) in Wisconsin.

2. LIQUID WATER CONTENT MEASUREMENTS

The number of seconds during which liquid water was observed in FIRE clouds between -25 and -35°C , is given in Fig. 1 as a function of amount detected. Data were obtained from a Rosemount Icing Detector (RICE), a Particle Measuring Systems' Forward Scattering Spectrometer Probe (FSSP), and two hot wire probes, the Johnson-Williams (J-W) and the King. Although the J-W and the King hot-wire probes have been the instruments of choice in past investigations of liquid water in cold clouds, they are limited by detection thresholds of 0.02 to 0.05 g m^{-3} , an order of magnitude higher than the RICE or the FSSP. The results given in Fig. 1 are taken from the FSSP data and illustrate the importance of measurements at smaller LWC; most of the liquid water observed at temperatures colder than -20°C was below the detection limits of the hot-wire probes. The data from which Fig. 1 was derived show the largest amounts of liquid water between -30 and -35°C , indicating that in this range, meteorology is more important than temperature.

The operating principles and calibration procedures of all but the RICE have been reported in the formal literature. The RICE collects water droplets and measures corresponding changes in the frequency of a vibrating cylinder. The upper noise limit was determined by examining all output obtained from the instrument at temperatures lower than -40°C where all water is assumed to be frozen. At the true air speed appropriate for the King Air, $\sim 100 \text{ m s}^{-1}$, the limit was found to be 3 mV s^{-1} . FSSP spectra of the same temperatures were used to determine ice particle contamination in the data from that instrument, resulting in a conservative threshold of 1.5 cm^{-3} particles per each size bin (3 to $45 \mu\text{m}$). Examination of the data taken at warmer temperatures indicated that the RICE and FSSP corrections were valid to -20°C .

As will be illustrated in another paper to be presented here, these measurements of supercooled liquid water were obtained within relatively thin altocumulus cloud layers found in association with cirrus cloud systems. Polarization lidar observations from the Wausau site reveal that the altocumulus frequently became incorporated in deep cirrus ice clouds as precipitating cirrus particles reached the height of the liquid layer. This process was observed to occur during all four of the deep cirrus cloud occurrences studied from Wausau during the FIRE IFO, and appears to have been important to the development of the cirrus at low levels.

3. ICE PARTICLE EVOLUTION

The types of ice crystals in the cold clouds and their size and number were determined from data obtained from two PMS imaging probes, 2D-C and P, and from collecting actual crystals *in situ* on oil-coated slides.

The evolution of ice particles in the cloud layers was examined using patterns in which the aircraft performed Lagrangian spirals, slowly descending through the layers while drifting with the ambient wind. The particle-size spectra derived from the imaging probes during one such Lagrangian spiral are given in Fig. 2a. Inhomogeneities have been removed by averaging each spectrum over the entire spiral. Measurements taken from the aircraft during the flight showed a zone of ice subsaturation between 7.4 and 8.8 km msl and ice supersaturations from 10 to 20% at other altitudes, all below the top of the cloud layer which the aircraft was unable to reach. In broadening with decreasing altitude the spectra shown are typical of those obtained in all of the flights. Again, typically, much of the growth occurs in the larger sizes. Examples of the particles, primarily bullet rosettes, collected during the same descent are also shown in Fig. 2b. Bullet rosettes were predominant in many of the collections and columns or plates in others.

4. ICE PARTICLE AGGREGATION

At all temperatures the imaging probe data from every flight gave evidence of particle aggregation; usually of bullet rosettes joined at their tips, as is illustrated in Fig. 2c and d. Aggregations of plates and columns were also observed, the former joined at edges and the latter end-to-end. At temperatures lower than -25°C the aggregations were almost always of two, equi-dimensional particles with concentrations unvaried with altitude, typically 0.1 to $0.5 \text{ } \ell^{-1}$. As temperatures warmed above -25°C , the number of aggregates increased as did the number of particles comprising them, their size, and their concentration in the total number of particles.

5. CONCLUSIONS

During the FIRE experiment, the microphysical characteristics of cold clouds have been examined, using the NCAR King Air. The clouds investigated ranged in temperature from -20 to -46°C . Liquid water was detected in these clouds at -35°C and may exist at even colder temperatures. Evaluation of the conditions under which it exists at such low temperatures is continuing.

Aircraft patterns in the form of Lagrangian spirals were used to interpret particle growth processes. Significant broadening of the particle size spectra was observed with minor changes in the spectra at small sizes. Virtually all of the broadening observed was attributable to ice particle aggregation which occurred at all temperatures. The crystals comprising the aggregates were of comparable size, joined either at tips or edges, and were usually two in number at temperatures lower than -25°C , increasing to three or more at warmer temperatures. The data strongly suggest that sintering is the mechanism through

which the crystals aggregate.

Aggregation appears to be important in the transfer of water mass from upper to lower levels in clouds. Investigation of the aggregation process is continuing in greater detail.

ACKNOWLEDGEMENTS

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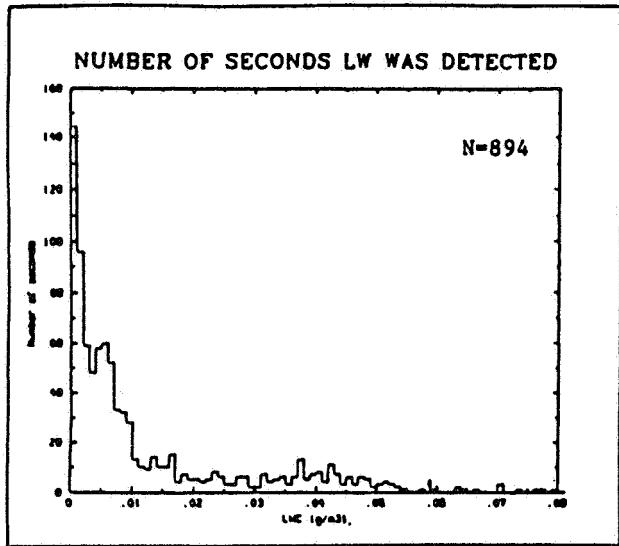


Fig. 1: Number of seconds in which liquid water was detected during FIRE flights as a function of LWC (g m^{-3}) in temperatures between -25 and -35°C . Bin widths are 0.001 g m^{-3} .

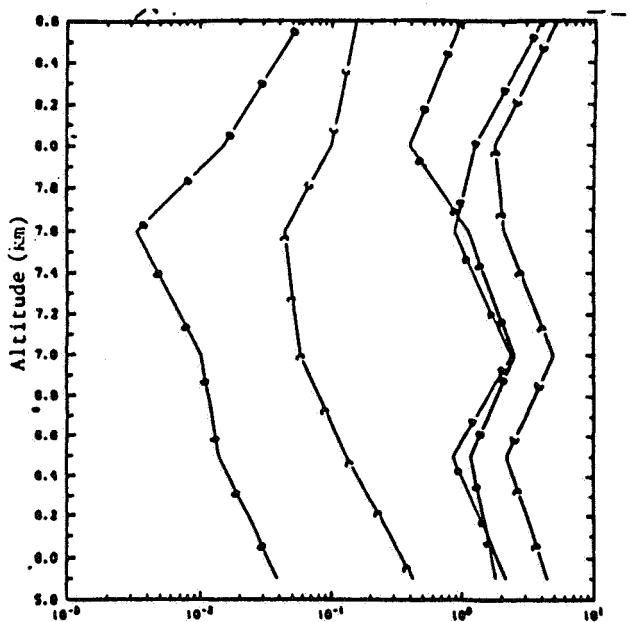


Fig. 2a: LAGRANGIAN SPIRAL, 2 November 1986. Particle concentration (number per liter) as a function of altitude. Size range (microns): a) $75 - 200$; b) $200 - 500$; c) $500 - 800$; d) > 800 ; e) total.

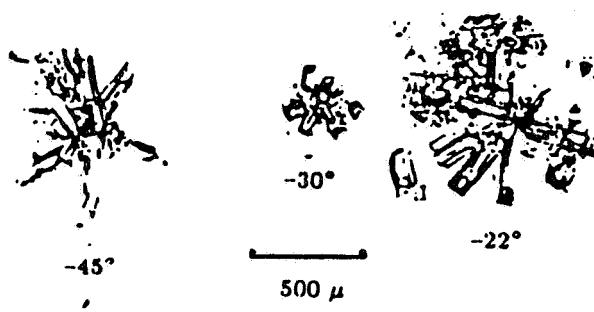


Fig. 2b: Particles collected in situ at temperatures given ($^\circ\text{C}$).

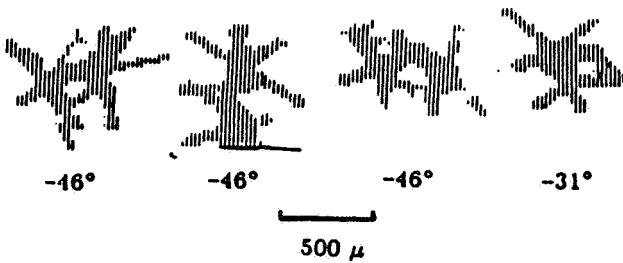


Fig. 2c: 2D-C probe images at temperatures given ($^\circ\text{C}$).

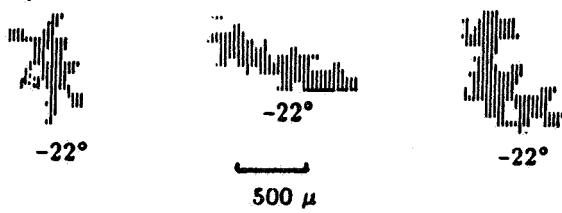


Fig. 2d: 2D-P probe images at temperatures given ($^\circ\text{C}$).

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